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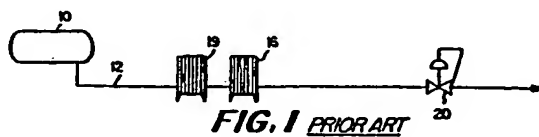
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(54) Method and apparatus for delivering a continuous quantity of gas over a wide range of flowrates.

(57) Method and apparatus for delivering high pressure gas to a point of use over a wide range of flowrates by storing (50) said gas as a cryogenic fluid, removing said cryogenic fluid by means of a single stage reciprocating piston-type pump/compressor (60) adapted to utilize liquid, vaporized liquid, a mixture of liquid and vaporized liquid, or supercritical fluid as the inlet fluid to said pump while maintaining the inlet fluid under cryogenic conditions. Blowby from the pump is recycled (100) to the system. Discharge fluid may also be recycled to the system.

**FIG. 1** *PRIOR ART*

BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a schematic representation of a prior art system for storing and delivering an industrial gas to a customer at pressures below storage vessel maximum allowable working pressure (MAWP).

Figure 2 is a schematic representation of a system for delivering product gas to a customer at medium pressure.

Figure 3 is a schematic representation of a prior art system for delivering a high pressure gas to a point of use.

Figure 4 is a schematic diagram of the system and method according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

As shown in Figure 1, a conventional system for providing a source of low pressure industrial gas, e.g., hydrogen, to a customer at a point of use includes storing the gas in an insulated container 10 in the form of a liquid. Liquid is withdrawn as needed from the tank 10 through line 12, passed through vaporizers 14 and 16 to the point of use through a control valve 20. During periods of low demand or no demand, liquefied gas in tank 10 vaporizes due to system heat leak, collects above the liquid and if overpressurization occurs, gas from tank 10 is vented safely for disposal.

As shown in Figure 2, a system for providing gas at the customer's point of use at pressures above storage vessel MAWP includes storing the gas in a cryogenic storage vessel 22, withdrawing vaporized cryogen from tank 22 through line 24, warming the withdrawn liquid in vaporizers 26 and 28 and raising the internal pressure of the warm gas by means of compressor 30 and dispensing the outlet of the compressor 30 through an after-cooler 31 and control valve 32. In a system according to Figure 2, liquid at approximately -400°F and 100 psig in the case of hydrogen is withdrawn from vessel 22. The gas is raised to ambient temperature by means of heat exchanger 26 and 28 while maintaining the internal pressure at approximately 100 psig and thereafter the pressure of the gas is raised from ambient to delivery pressure by means of compressor 30. Several stages of compression with intercooling may be necessary depending upon use pressure and fluid properties.

As shown in Figure 3, a system for delivering a high pressure gas, e.g. hydrogen at 2200 psi, includes a cryogenic storage vessel 34 wherein liquid is withdrawn from the storage vessel 34 by means of conduit 36, passed to a cryogenic pump 38, the discharge of the pump conduit 40 being a gas at approximately -350°F and 2700 psig thereafter raising the temperature of the gas in heat

exchangers 42 and 44, with the product discharged from vaporizer 44 being at approximately 2600 psig and ambient temperature. Product thus produced can be stored in a series of high pressure storage containers 46 for satisfying the customer's needs which can be delivered through a control valve 48. In a system according to Claim 3 it is possible for 30% or more of the product in tank 34 to vent as vapor and be lost.

As shown in Figure 4 the apparatus of the present invention includes a cryogenic storage vessel 50 which has a system 52 consisting of a conduit 54 and control valve 55 connected to the tank 50 so as to withdraw liquid or supercritical fluid from the tank and deliver the fluid through a conduit 56 to the inlet 58 of a pump/compressor 60. System 52 includes a conduit 62 and control valve 64 adapted to remove vaporized cryogen contained above the liquid L in tank 50 or supercritical fluid for delivery through conduit 66 to the inlet 58 of the pump/compressor 60. System 52 may be insulated so that both the liquid and the vapor withdrawn from the vessel 50 can be maintained under cryogenic conditions. The outlet of pump 60 is connected through conduits 70, 72 and vaporizers 71, 73 through a control valve 74 to deliver gaseous product to the customer. The system optionally includes a gas storage vessel 76 to maintain an inventory of gas for use by the customer or to act as a surge vessel to contain thermally expanded product during system shutdowns, providing ventless operation.

As shown in Figure 4, tank 50 typically includes a pressure building system including a withdrawal conduit 86, heat exchanger 88, control valve 90, return conduit 92 to pressurize the storage vessel 50 by withdrawing liquid and allowing it to warm up, expand and be returned as vapor to the vapor space V of tank 50. The optional auxiliary system can include a second loop consisting of conduit 78, heat exchanger 80, valve 82 and return conduit 84 to aid in maintaining pressure on the storage vessel 50. This auxiliary pressure build system may be designed to provide minimal pressure drop with a controlled heat input to maximize the flow capacity of pump/compressor 60 operating in vapor only mode.

The apparatus of Figure 4 includes a conduit 100 to take piston ring leakage or blowby from the pump/compressor which is preferably a single stage reciprocating piston-type machine having a volume displacement of about 40 to 200 ACFH (actual cubic feet per hour) (producing 26,000 SCFH mass flowrate 135 psig at -400°F gaseous inlet condition for hydrogen feed). The blowby in conduit 100 is passed through a blowby cooler 102 where the blowby is cooled by heat exchange with the discharge in conduit 72 from the

is continuously present. The pressure-fed capability of the present invention can yield higher flow rates than achieved in practice by gravity-fed pumps, and cavitation no longer applies since the full storage container pressure is used to force feed the pump/compressor. The storage container pressure is usually well above the liquid saturation pressure.

As shown in Figure 4, the optional device to control the system flow includes internal recycle by a conduit 112, valve 114, and conduit 116. If a user is drawing very little product while the pump/compressor is operating in a pure vapor inlet mode and the system is not to be shut down, the recycle loop can be used to recycle a portion of discharge back to the inlet of the pump/compressor 60 and effectively reduce the net system flow to match the low usage rate. This method can be performed either by simple back pressure regulation or with a pressure control valve monitoring system discharge pressure and customer use flow.

As shown in Figure 4, piston ring leakage (blowby) is returned to the system for recompression via conduit 100 to avoid a venting loss, but its return point is variable to allow greater flexibility depending upon the pump/compressor inlet option and storage container condition. If the pump/compressor is providing more of a pumping function by having mostly liquid at the inlet, the storage container pressure will generally not need to be increased, since the pressure reduction effect of removing liquid from the tank is small. Therefore, it is not desirable to add the blowby back to the tank, since pressure will increase and the tank could vent. In this instance, the blowby is introduced into the suction of the pump/compressor 60 so it is not a venting loss. The amount this blowby recycle decreases the pump/compressor flow is negligible compared to the flow potential using mostly liquid.

If the pump/compressor is providing more of a compressing function by having mostly vapor at the inlet, the storage container pressure will need to be maintained with cold gas to provide high inlet vapor density to the unit and achieve the desired flow rate. Returning the blowby to the top of the tank defeats this purpose by recycling relatively warm gas eventually back to the suction of the pump/compressor and reducing the flow capability too far. Therefore, the blowby can be bubbled back through the cryogenic liquid, thus promoting the production of saturated gas in the top of vessel 50 by boiling a portion of the liquid in the vessel. In this mode, the blowby is the primary means of maintaining storage container pressure during compressor-type operation.

In either case, the blowby does not constitute a venting loss. Also, the blowby is first cooled against the immediate pump/compressor discharge

flow in a blowby aftercooler 102 to recover refrigeration available in the discharge stream before being recycled back to the system in either fashion. The blowby lines may be thermally insulated to preserve the coldest recycle temperature possible. Check valves set to operate at about 5 psig opening pressure above the back pressure on them can be used in both blowby return lines to back pressure the piston blowby slightly.

Under extremely high flow conditions it may be beneficial to return blowby to the vapor space of tank 50 or into conduits 62, 66 by means of insulated or non-insulated conduits. In another mode it may be desirable to return blowby to the liquid in tank 50.

As shown in Figure 4 in dotted lines, an alternate method of controlling compressor flow rate through compressor regulation can be achieved by taking warmed product gas through conduit 120 or 121 and control valve 122 and returning the warmed product gas through conduit 124 to a valve system, e.g. a 3-way valve 126 to permit the operator to select warm or cold gas to (by pressure regulation) control compressor flow rate as described in connection with Figure 4. A similar system permits automatic defrost for continuous usage systems with two pump/compressors in parallel. In this mode, one machine can be on-line for several days. When the ice buildup is excessive on the unit and discharge piping (a function of continuous running hours), the second machine can be brought on line. As the second unit cools down and produces higher flows, the first machine will internally recycle more warm gas. When the second machine is providing full customer flow, the first machine will approach full recycle. The first unit will then defrost in short order and can be placed on standby for future use, when needed.

While the system has been described as being used to compress cold, gaseous hydrogen, this system could be used for cryogenic pressurization of helium, nitrogen, oxygen, argon, carbon dioxide, methane, natural gas, hydrogen, hydrocarbons and other cryogens including mixtures of these cryogens, either as liquid, vapor or a mixture of a liquid and vapor of the cryogens or supercritical fluid.

A system according to the present invention operates at a nominal operating temperature near the saturated temperature of the product at the storage container pressure. This can vary from about +70 °F to -450 °F. The design temperature range is from -452 °F to +400 °F with the inlet to the pump/compressor being either superheated gas, saturated gas or liquid, subcooled liquid, supercritical fluid, or mixtures thereof.

In general, a typical customer station tank pressure is acceptable as the inlet pressure with the understanding that higher inlet pressures can yield

said pump/compressor.

4. A system according to Claim 3 including insulated means for returning said blowby from said cooling means to said storage container or said pump/compressor. 5
5. A system according to Claim 1 including means to use said pump/compressor outlet gas to control pump/compressor flowrates by regulating density of the inlet fluid to said pump/compressor. 10
6. A system according to Claim 1 including means to recycle warmed outlet fluid from said pump/compressor to control compressor flowrate by regulating density of the inlet fluid to said pump/compressor. 15
7. A system according to Claim 1 wherein said first means is a fluid flow control valve. 20
8. A system according to Claim 1 wherein said second means is a fluid flow control valve. 25
9. A method for delivering high pressure gas as product to a point of use over a wide range of flowrates comprising in combination:
 - storing said gas as a liquid or liquid and vaporized gas or as a supercritical fluid ; 30
 - removing from said vessel a fluid selected from the group consisting of liquid, vaporized liquid, a mixture of liquid and vaporized liquid or supercritical fluid and directing the withdrawn fluid, maintaining temperatures below ambient, to the inlet of a single stage reciprocating piston-type pump/compressor; and 35
 - varying the inlet to said pump/compressor to be either liquid, vaporized liquid, a mixture of liquid and vaporized liquid or supercritical fluid to maintain the mass flowrate from the pump/compressor. 40
10. A method according to Claim 9 including directing blowby from said pump/compressor to either said vessel liquid space, vaporized liquid space or the inlet fluid for said pump/compressor. 45
11. A method according to Claim 10 wherein said blowby is cooled by heat exchange with fluid exiting said pump/compressor. 50
12. A method according to Claim 9 including directing a portion of said pump/compressor discharge to said inlet fluid to aid in controlling pump/compressor flowrate. 55
13. A method according to Claim 9 including warming said pump/compressor discharge and directing a portion of said warmed discharge to said inlet fluid to aid in controlling pump/compressor flowrate.

FIG. 4

